WATERSHED AND WATER QUALITY MODELING ANALYTICAL REPORT

PREPARED FOR:

INDIANA DEPARTMENT OF ENVIRONMENTAL MANAGEMENT
OFFICE OF WATER QUALITY
2525 NORTH SHADELAND AVENUE
INDIANAPOLIS, INDIANA 46219

PREPARED BY:

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TRIAD ENGINEERING INCORPORATED
PROJECT NO. I023557.BG005

SEPTEMBER 2003

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Section 1.0
ACKNOWLEDGMENTS

The Trail Creek Watershed *E. Coli* model completed for IDEM would not have been successful without the assistance and guidance provided by Triad Engineering Incorporated (Triad) specifically, Tina Reese, Willie Gonwa and Ryan Eckdale-Dudley. Their efforts in coordinating tasks, obtaining data and providing local guidance were helpful throughout the project. In addition, the data assimilation and modeling efforts at HydroQual could not have been completed without the assistance of Ying Yi. Overall model development and calibration direction and management were completed by Andrew Thuman of HydroQual.

Section 2.0
INTRODUCTION

Watershed modeling is the quantitative component of a TMDL. The watershed model couples the landside and receiving stream models and is utilized to determine the response of a system to a causative factor, such as point or nonpoint source loadings and the subsequent instream concentrations. These quantitative modeling frameworks are useful tools for assessing the instream environmental conditions due to point and nonpoint source discharges, as well as to assess the role of remedial programs aimed at correcting environmental pollution problems. The tasks associated with watershed modeling in Trail Creek include: the assessment of current conditions and estimating existing *E. Coli* bacteria from various sources; reproducing existing or past watershed conditions (model calibration and validation) and the determination of the Trail Creek watershed TMDL; projecting future conditions due to *E. Coli* bacteria load reduction measures; and evaluating the value of alternative *E. Coli* bacteria loading scenarios or assessing the effectiveness of BMPs.

The Indiana Department of Environmental Management (IDEM) is required to establish a Total Maximum Daily Load (TMDL) generating process and implementation procedure that follows the federal guidelines and regulations. Waterbodies that do not meet established water quality standards must be identified and watersheds draining to the Great Lakes must also comply with the Great Lakes Initiative. Lake Michigan specific TMDL Guidelines (USEPA, 1995) have been established and Trail Creek has been identified through the 303(d) listing process as being impaired for the parameter of concern, *E. Coli*, which has a maximum standard of 235 #/100mL in any one sample in a 30-day period and 125 #/100mL as a geometric mean based on not less than five samples equally spaced over a 30-day period.

E. Coli bacteria problems can result from pollutant discharges from numerous and varied sources existing in all major land use categories. It is necessary to identify and understand the cause and occurrence of *E. Coli* water quality standard exceedances to establish a defendable TMDL for the Trail Creek watershed. Previous studies have identified potentially significant sources of *E. Coli*. Sources can be divided into two categories: point and nonpoint sources. Point sources include municipalities with combined sewer overflows (CSOs), sanitary sewer over flows (SSO), industrial wastewater treatment plant discharges, and/or improperly disinfected wastewater treatment plant effluent. Other potential point sources may include failing septic systems, direct contamination by waterfowl, concentrated animal feeding operations (CAFO), or diffuse sources that may enter a waterbody at a discrete location (e.g., field drainage systems). Nonpoint sources of *E. Coli* bacteria are diffuse and are not usually identified as entering a water body at a discrete location, including urban/suburban runoff and rural runoff from livestock pastures, cropfield where manure application is practiced, animal feedlots, etc. It is anticipated that the Trail Creek watershed has the potential to exhibit both widespread and localized impacts. Additional challenges to the development of an *E. Coli* TMDL are presented through wet versus dry weather impact variation, as well as the consideration of the time-variable nature of the pollutant and its sources.

A TMDL is the total pollutant load from point and nonpoint sources that a water body can assimilate while maintaining its designated use (water quality standards). It also includes an appropriate margin of safety. The focus of the TMDL is the reduction of pollutant inputs to a level (or “load”) that fully supports the designated use of a given water body. The mechanisms (implementation plan) used to address water quality problems after the TMDL is developed can include a combination of BMPs and/or effluent limits and monitoring required through NPDES permits.

Section 3.0
STUDY AREA

Trail Creek is a tributary of Lake Michigan in La Porte County in northwestern Indiana. An east and west branch combine and flow north for approximately 3 miles through Michigan City before discharging into Lake Michigan. Trail Creek is maintained as a salmonoid fishery stream by the Indiana Department of Natural Resources (IDNR) and is protected by the appropriate water quality standards.

Figure 1 presents a map of the study area. The land use, stream network, and watershed characteristics associated with the watershed were obtained from the USEPA BASINS database. The watershed was divided into three sub-watersheds: an east branch, west branch, and main branch. The east and west branch sub-watersheds are mainly croplands and forests and the main branch sub-watershed is primarily developed area including industrial, residential, and other urban land uses. All three subwatersheds also have a small percentage of transitioned land uses. Transitional land use includes areas of sparse vegetative cover (less than 25 percent of cover) that are dynamically changing from one land cover to another, often because of land use activities. There are two USGS gaging stations in Trail Creek, one active and one discontinued. The discontinued gage is located about 4 miles from the mouth at Springland Avenue (USGS 04095300), which has flow records until 1994; the active gage is located near the mouth of the creek in the Harbor (USGS 04095380) with flow records from 1994 to the present. The flow movement near the mouth of the creek is largely influenced by Lake Michigan and at times the flow direction may be temporarily reversed, which complicates the use of this flow gage for watershed runoff modeling.

Previous sampling studies of *E. Coli* in the Trail Creek watershed have been summarized by Triad Engineering Incorporated (Triad, 2003). The data were collected at 31 locations on 169 different dates between the period of March 18, 1998 and October 3, 2002. Figure 1 presents the USGS gaging stations and *E. Coli* sampling locations.

Section 4.0
TRAIL CREEK WATERSHED MODEL

The Trail Creek watershed model is based on two public domain models: a watershed model BasinSim 1.0 (GWLF), and a receiving water quality model WASP6. BasinSim 1.0 is a product of National Oceanic and Atmospheric Administration (NOAA) and WASP6 is distributed by the USEPA. BasinSim 1.0 was used to compute time variable runoff quantity in the Trail Creek watershed due to factors such as rainfall, land use/cover and soil type. The WASP6 model was used to simulate water quality in the major branches of the watershed due to watershed loadings, dilution and chemical/physical/biological reactions. The calculated runoff flow from the BasinSim 1.0 model was used as input into the WASP6 model to perform water transport calculations. The Trail Creek watershed was divided into three sub-watersheds: an east branch, west branch, and main branch. The BasinSim 1.0 model simulates daily stream flows in the three sub-watersheds with the calculated total sub-watershed flow distributed evenly along the branch length as the runoff inflow in the WASP6 model.

In an effort to identify a time period for the model calibration, a summary table of annual average flow, total annual rainfall, and *E. Coli* data from 1998 to 2001 is presented in Table 1. Year 2000 was selected as the calibration year because there are more sampling stations and samples of *E. Coli* data for this year than the other 3 years. However, since BasinSim 1.0 model uses a hydrologic year, which starts in April, the watershed landside model was applied from April 1999 to March 2001. Runoff flow output for the year 2000 was then extracted and input into the WASP6 model to simulate time and spatially variable instream *E. Coli* concentration for the year 2000.

Table 1
SUMMARY OF AVAILABLE DATA FOR YEAR 1998 – 2001

Year	Annual Average Flow (cfs)	Annual Total Rain Fall (inches)	No. of *E. Coli* Sampling Stations	No. of *E. Coli* Samples
1993[1]	109	39.95	NA	NA
1998[2]	63	28.96	10	368
1999[2]	62	25.39	7	215
2000[2]	56	29.92	27	457
2001[2]	47	34.55	11	168

1 USGS flow from discontinued upstream gage No. 04095300 and adjusted rainfall from NCDC City of LaPorte gage
2 Adjusted USGA flow from current harbor gage No. 04095380 and rainfall from Michigan City WWTP

4.1 BASINSIM (GWLF) MODEL

BasinSim 1.0 is a Windows based simulation system that uses the Generalized Watershed Loading Functions (GWLF) model. The GWLF model is a mid-range watershed model that is more detailed than empirical export coefficient approaches (e.g., unit area loadings) but less complex than mechanistic (mass balance) simulation models. GWLF simulates the hydrologic cycle in a watershed, predicting streamflow based on precipitation, evapotranspiration, land and soil characteristics. Streamflow consist of runoff and discharge from groundwater. The Natural Resource Conservation Service Curve Number Equation is used to calculate watershed runoff quantity and groundwater discharge is determined from a watershed water balance. GWLF can also predict nutrient loads from surface runoff, groundwater, point sources, and septic systems with the hydrologic cycle and input loading functions. In the application of the model to the Trail Creek watershed, only the hydrologic component was used and the computed runoff quantity was coupled with an assigned *E. Coli* concentration to generate bacteria loads for the instream water quality model, WASP6.

The GWLF model computes runoff using the following equation:

$$Q_{kt} = \frac{(R_t + M_t - 0.2 * DS_{kt})^2}{R_t + M_t + 0.8 * DS_{kt}}$$

where R_t and M_t are rainfall and snowmelt on day t. The detention parameter DS_{kt} is determined from the curve number CN_{kt} from source area k on day t:

$$DS_{kt} = \frac{2540}{CN_{kt}} - 25.4$$

Groundwater discharge is obtained from a lumped parameter watershed water balance. Daily water balances are calculated for unsaturated and shallow saturated zones. Infiltration to the unsaturated and shallow saturated zones equals the excess, if any, of rainfall and snowmelt less runoff and evapotranspiration. Percolation occurs when the unsaturated zone water exceeds field capacity. The shallow saturated zone is modeled as a linear groundwater reservoir. Figure 2 presents the water balance components.

Water balances for the unsaturated and shallow saturated zones are:

$$U_{t+1} = U_t + R_t + M_t - Q_t - E_t - PC_t$$
$$S_{t+1} = S_t + PC_t - G_t - D_t$$

In these equations, U_t and S_t are the unsaturated and shallow saturated zone soil moistures at the beginning of day t and R_t, M_t, Q_t, E_t, PC_t, G_t, and D_t are rainfall, snowmelt, watershed runoff, evapotranspiration, percolation into the shallow saturated zone, groundwater discharge into the stream and seepage flow to the deep saturated zone, respectively, on day t.

4.1.1 Model Input

There are three basic input files required to run BasinSim: a weather file, transport file, and nutrient file. Weather and transport files were created according to the observed data in the

Trail Creek to simulate the hydrologic cycle. The nutrient file was not used because *E. Coli* is being simulated and concentrations were assigned to the calculated GWLF runoff to develop the runoff (NPS) loads for the WASP6 model.

Weather Data File

The weather data file consists of daily air temperature and precipitation for Trail Creek. This data was obtained from the National Climatic Data Center (NCDC) for a weather station in the City of LaPorte (COOPID No. 124837) for April 1, 1992 to March 31, 1994 and from the Michigan Wastewater Treatment Plant Weather Data CDs from April 1, 1999 to March 31, 2001. Figure 3a and 3b present the air temperature and rainfall used as model input for the two separate calibration and validation periods.

Transport Data File

There are three transport data files for the three sub-watersheds. The transport data file includes parameters such as land use types, areas, runoff curve numbers, erosion product (K*LS*C*P) for each runoff source, groundwater recession and seepage coefficients, the available water capacity of the unsaturated zone, the sediment delivery ratio, monthly values for evapotranspiration cover factors, average daylight hours, growing season indicators and rainfall erosivity coefficients. The erosion product parameters from the Universal Soil Loss Equation along with the table and equation numbers form the BasinSim GWLF manual for typical values are presented below:

K – Soil erodibility factor (Table B-10);
LS – Calculated parameter as a function of slope length and percent slope (Equations B-6 and B-7);
C – Cover and management factor (Table B-11 and B-12); and
P – Supporting practice factor (Table B-13).

<u>Land Use Types (Runoff Sources)</u>

The runoff sources (same as land use types) in Trail Creek were classified as agriculture, forest, transitional, and developed. Figure 1 presents the land use types for the Trail Creek watersheds. The east and west branch sub-watersheds are mainly forest and agriculture, and the main branch sub-watershed is mainly developed area. All three subwatersheds have a small percentage of transitioned land uses. Transitional land use includes areas of sparse vegetative cover (less than 25 percent of cover) that are dynamically changing from one land cover to another, often because of land use activities.

<u>Areas</u>

Areas in hectares for each runoff source (land use) for the three sub-watersheds were calculated for the Trail Creek watershed from land use shape files downloaded from the Lake RIM website. The detailed land use categories obtained from the website were modified and grouped into five general land use categories.

Runoff Curve Numbers

Runoff curve numbers proportionally determines the runoff amount. Usually runoff in urban areas is higher than that in forest and farm areas. Runoff curve numbers are given in the BasinSim GWLF manual Appendix B-2 to B-5 for different land use/cover and soil hydrologic group combinations. The land use and soil hydrologic group information for the Trail Creek watershed were obtained from the USEPA Basins database. The curve numbers are calculated for each land use type for the three sub-watersheds by grouping different land use, soil hydrologic group combinations and a weighted average was performed for each land use type within each sub-watershed. Table 2 presents the area and runoff curve numbers for each of the three sub-watersheds used for the calibration and validation periods.

Table 2

RUNOFF CURVE NUMBERS USED IN THE GWLF MODEL

	Land Use	Area (ha)	Curve No.		Land Use	Area (ha)	Curve No.		Land Use	Area (ha)	Curve No.
Main Branch	Agriculture	935	61	East Branch	Agriculture	3284	61	West Branch	Agriculture	3725	61
	Forest	750	30		Forest	2018	30		Forest	1670	30
	Transitional	145	59		Transitional	36	59		Transitional	161	59
	Developed	1648	83		Developed	277	83		Developed	593	83

Erosion Product K*LS*C*P

K, LS, C, P are the standard values for soil erodibility, topographical, cover and management, and supporting practice factors for soil loss calculations. Because nutrients are not modeled in the landside model for Trail Creek, this product is not essential in simulating hydrologic cycles in the Trail Creek watershed model for *E. Coli*.

Groundwater Recession and Seepage Coefficient

The recession coefficient was estimated from streamflow records at the upstream gage (No. 04095300) in the year 1993 during four hydrograph recessions between March and May. The calculated recession coefficients were: 0.25 for March 23-27, 0.27 for April 1-5, 0.43 for April 20-24 and 0.21 for May 5-9. All of these calculated recession coefficients had correlation coefficients (r) greater than 0.94. An average groundwater recession value of 0.3 was assigned for the east, west and main branches for the GWLF model calibration and validation. The seepage coefficient can be adjusted during the calibration to match the observed flow data and a final value of zero was used, which indicates that no rainfall is lost to deep aquifer storage.

Initial Unsaturated and Saturated Storage, Initial Snow Cover, Unsaturated Water Capacity

The initial conditions for unsaturated storage, saturated storage and snow were set to default values given in the manual, which do not affect the year 1993 calibration and 2000 validation. The default value for initial unsaturated and saturated storage was set at 10 cm and initial snow cover was set at 0 cm. The unsaturated water capacity was set at 15 cm based on the calibration to 1993 and validation to 2000.

Sediment Delivery Ratio

The sediment delivery ratio is required in the transport file for the calculation of sediment output. It is calculated in the GWLF model based on the area of the watershed although unused because of the current application to *E. Coli*.

Monthly Evapotranspiration Cover Factors

The evapotranspiration (ET) cover coefficient is the ratio of water loss by evapotranspiration from ground and plants compared to what would be lost by evaporation from an equal area of standing water. ET cover coefficients vary by land use type and time period within the growing season. Typical values are between 0 (for impervious surfaces) and 1 (water). Monthly averages weighted by land use percentages are required in the transport data file for the entire watershed. The coefficients were obtained from Appendix B-6 to B-8 in the GWLF manual and the final calibration values are presented in Table 3. Calibration of the ET coefficients was based on reproducing the observed creek flows (peak and base) with the GWLF model. The original ET coefficients (area weighted) from the GWLF manual were 0.25/0.59 (dormant/growing season) for the main branch, 0.30/0.96 for the east branch, and 0.29/0.90 for the west branch.

Table 3
EVAPOTRANSPIRATION COVER COEFFICIENTS USED IN GWLF MODEL

	Month	ET Cover Coeff		Month	ET Cover Coeff		Month	ET Cover Coeff
Main Branch	Apr	0.7	**East Branch**	Apr	1.0	**West Branch**	Apr	1.0
	May	0.7		May	1.0		May	1.0
	Jun	0.7		Jun	1.0		Jun	1.0
	Jul	0.7		Jul	1.0		Jul	1.0
	Aug	0.7		Aug	1.0		Aug	1.0
	Sept	0.7		Sept	1.0		Sept	1.0
	Oct	0.7		Oct	1.0		Oct	1.0
	Nov	0.4		Nov	0.5		Nov	0.5
	Dec	0.4		Dec	0.5		Dec	0.5
	Jan	0.4		Jan	0.5		Jan	0.5
	Feb	0.4		Feb	0.5		Feb	0.5
	Mar	0.4		Mar	0.5		Mar	0.5

Average Daylight Hours

Monthly daylight hours were obtained from Table B-9 in the GWLF manual with the latitude of Trail Creek as 42 degrees north and are presented in Table 4.

Table 4
AVERAGE DAYLIGHT HOURS USED IN GWLF MODEL

Month	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Daylight Hours	13.1	14.3	15	14.6	13.6	12.3	10.9	9.7	9	9.3	10.4	11.7

Growing Season Indicator

Growing season indicators were estimated based on typical planting periods in northern Indiana obtained from Purdue University and USDA on-line information. April through October was assigned 1 indicating the growing season and November through April as 0 indicating the dormant season.

Rainfall Erosivity Coefficient

Rainfall erosivity is a coefficient in soil erosion. Since sediment in Trail Creek watershed was not modeled, this parameter was not essential for the streamflow calculation. It can be estimated from Table B-14 in the GWLF manual based on the erosivity zone of Trail Creek, which is zone 15 according to Figure B-1 in the GWLF manual.

Nutrient Data File

The nutrient data file is not used in streamflow calculations, but is a required input as part of the BasinSim 1.0 input files even though nutrients are not modeled in this application for the Trail Creek TMDL. The Trail Creek watershed nutrient data file was created according to the required input format but without estimating model-specific coefficients and parameters because nutrients are not modeled for the Trail Creek Watershed *E. Coli* TMDL. This input file does not effect the calculations of runoff flow and, therefore, the input values assigned will not affect the model output of runoff flow.

4.1.2 Model Calibration

The current flow gage in the Trail Creek watershed is located in Michigan City Harbor (No. 04095380), which is affected by water levels in Lake Michigan. That is, measured river flows at this gage can be less than or equal to zero depending on water levels in the lake. This complication limits the use of this flow gage for GWLF runoff calibration in the year 2000. Historically, there was an upstream flow gage at Michigan City (No. 04095300), which was not influenced by the lake, but this gage was discontinued in 1994. In order to calibrate the GWLF model, the model was calibrated to a period from April 1, 1992 to March 31, 1994 for the 1993 annual cycle using the upstream gage and then the calibration parameters obtained were used to calculate runoff for the 2000 modeling period (April 1, 1999 to March 31, 2001). This process was necessary to determine the GWLF model calibration coefficients from a flow record that was not influenced by Lake Michigan water levels. The next sections describe the GWLF model calibration coefficients and resulting runoff flow calibration to 1993 and validation to 2000.

Calibration and validation of the GWLF model was to stream flow for the two periods discussed above: 1993 and 2000. There are uncertainties in the GWLF calibration such as only one rainfall record for the entire watershed that is located near the mouth, and potential small-scale weather patterns, land use and soil types. In addition, as mentioned before, flow at the active USGS gage station is largely affected by water levels in Lake Michigan; sometimes flow direction is even reversed. Figure 4 presents the comparison of USGS flow data at the mouth of the creek (active) and at Springland Avenue (retired). Although the time of the data is different because the gage station at Springland Avenue was discontinued in 1994, the magnitude of the flow at the two stations indicates that the measurements at the mouth of Trail Creek are indeed influenced by the lake and are typically greater. To compare the model results with the active gage data at the mouth of Trail Creek for the validation to year 2000, some kind of flow adjustment was needed. This adjustment factor was based on comparing the flow from the retired gage before the active gage began. The retired gage flow on September 30, 1994 was 36 cfs and the active gage flow was 103 cfs on October 1, 1994, which is a difference of 67 cfs. An adjustment flow of 65 cfs is used to adjust the active gage data for comparison with the model results.

Figures 5a through e present the GWLF runoff calibration results and Figures 6a through e present the validation results. The first figure in each set contains the GWLF calculated flows (blue line) and observed USGS flows (red line), the second through fourth presents the GWLF calculated flows for the west, east and main watersheds, and a bar chart of GWLF calculated and observed monthly runoff volumes. As presented in these figures, the model captures the peaks and has the same patterns as observed in the data although the proper magnitude is not always obtained, which may be due to local weather patterns not reflected in the rainfall data used for both the calibration and validation. A base groundwater flow was assigned in the model based on the calibration to 1993 for the east and west branches of 15 cfs in each branch for both the 1993 and 2000 modeling periods. This was also necessary because the GWLF model assumption of a simple lumped parameter groundwater model results in model flow calculations during periods of minimal rainfall as near zero. As discussed above, the 2000 flow data available to validate the GWLF model is not ideal due to the lake influence and calibration to this data may not result in the best agreement. Use of the year 2000 flow data from the harbor was necessary because the year 2000 was selected to calibrate the WASP6 model based on the best *E. Coli* data availability as discussed in Section 4.0. Overall the GWLF model reasonably reproduces the observed creek flows in 1993 and 2000. That is, the calculated GWLF flows reasonably reproduce the observed hydrographs in 1993 and 2000 for peak and base flows in addition to the recession of flows after storm events. Table 5a and b summarize monthly and annual runoff volumes from the GWLF model and the USGS flow data for the years 1993 and 2000. Although the month-to-month volume comparisons are not always similar, annual runoff volumes are within less than 4% of the observed volumes for both 1993 and 2000.

Table 5a
Comparison of Monthly and Annual Volumes of the Model and Data in 1993

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
Model (MG)	4776	665	3136	4001	917	3315	942	737	1223	2722	2464	1331	26230
Data (MG)	3037	1029	2727	2879	1256	6162	1411	963	1359	1835	1602	1438	25698

Table 5b Comparison of Monthly and Annual Volumes of the Model and Data in 2000													
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Annual**
Model (MG)	729	828	858	1239	810	3347	854	729	817	839	911	884	12845
Data (MG)	998	1075	1040	1494	1310	2471	957	692	933	657	929	735	13292

4.2 WASP6 MODEL

Instream *E. Coli* concentrations in Trail Creek are simulated with WASP6 for the year 2000 using the runoff flows computed with the calibrated and validated GWLF model. However the WASP6 model was not validated with an additional dataset as was the GWLF model. Although validation of the WASP6 model was not completed, the time-variable calibration of the model for the year 2000 encompassed a wide range of runoff events and, therefore, the model was well tested for a variety of runoff conditions.

WASP6 is an enhanced Windows version of the USEPA Water Quality Analysis Simulation Program (WASP). The time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are present in the basic program. Stream flow is assigned based on the computed GWLF runoff and groundwater flows. The three reaches in the Trail Creek watershed were segmented for application of the WASP6 model with length, width, and depth assigned for each model segment. Segment length is assigned to maintain model stability and minimize numerical dispersion. The water quality component of the WASP6 model includes bacteria die-off as a function of temperature as the main loss rate with loading sources from runoff (NPS) loadings and point sources. Time-variable output from the model is compared with the observed watershed data for calibration to the instream *E. Coli* concentrations.

4.2.1 Water Quality State Variables

The EUTRO model in WASP6 was used to calculate *E. Coli* concentrations in Trail Creek. This modeling component contains nine systems: Inorganic and organic forms of nitrogen and phosphorus, phytoplankton, ultimate BOD (BODu) and salinity (tracer). For Trail Creek, the ultimate BOD system is used to model *E. Coli* with the other systems not simulated and set at constant values to not interfere with the *E. Coli* calculations in the BODu system. Salinity is kept in the model as a tracer to check on mass balances, which is completed by assigning a constant value of 100 to all boundary and initial conditions, and all sources. Results from this test indicated that the model is maintaining mass balances in all model segments throughout the entire simulation period. The general mass balance equation used in the model to solve the state variable in each segment is:

$$\frac{\partial C}{\partial t} = -\frac{\partial}{\partial x}(U_x C) - \frac{\partial}{\partial y}(U_y C) - \frac{\partial}{\partial z}(U_z C) + \frac{\partial}{\partial x}(E_x \frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(E_y \frac{\partial C}{\partial y}) + \frac{\partial}{\partial z}(E_z \frac{\partial C}{\partial z}) + S_L + S_B + S_K$$

where:

C =	concentration of the water quality constituent, mg/L;
t =	time, days;
U_x, U_y, U_z =	longitudinal, lateral, and vertical advective velocities, m/day;
E_x, E_y, E_z =	longitudinal, lateral, and vertical diffusion coefficients, m^2/day;
S_L =	direct and diffuse loading rate, g/m^3-day;
S_b =	boundary loading rate (including upstream, downstream, benthic, and atmospheric), g/m^3-day; and
S_K =	total kinetic transformation rate; positive is source, negative is sink, g/m^3-day.

WASP6 is a multi-dimensional model and was applied with one surface water segment only (one-dimensional) for the Trail Creek Watershed. In this application, advection is the only transport process for the variables with dispersion considered negligible.

4.2.2 Model Input

The WASP6 model requires input for initial conditions, streamflow, point and nonpoint source loads, boundary conditions, segments characteristics (including river geometry, parameter specification), temperature time functions, integration time step, and print intervals.

Model Segmentation

The model is divided into 36 segments. Figure 7 presents the segmentation of the model, and the length of each segment. Segmentation starts from the mouth of the creek, going upstream along the main stem (segments M1 through M12), then splits at the junction of the west (W1 to W10) and east branches (E1 to E14). Each of the segments is about one kilometer long. Segments M1 and M2 are set at 0.8 and 1.2 kilometers, respectively, because the geometry near the mouth of the creek changes rapidly around 0.8 kilometers from the mouth.

Creek Geometry

The model requires segment volume, velocity, and depth for each segment. Segment volume is the product of segment length, width, and depth. Estimation of segment width and depth is based on geometry studies performed earlier (HydroQual, 1984; Triad, 1993) and/or from USGS maps. The HydroQual surveys were completed in 1981 and 1983, and the Triad survey completed in 1993. These surveys provide depth and width information for some locations in the creek. In addition, more general width information is obtained by estimating stream width from USGS topographical maps. Figure 8 presents the depth and width data from the surveys and USGS maps. Depth and width averages were taken from the different geometry data sources for different sections of the creek and assigned to the segments. Most of the data obtained are for the downstream portion of the main branch, and only one data point in the west branch is available. Upstream in west branch, a minimum width of 5 feet and depth of 0.5 ft was assigned. Due to lack of information, geometry of the east branch is set to have the same values as the west branch. Wherever there is lack of data for segments, linear interpolation is performed based on the river miles of each segment.

Streamflow

Runoff inflow into each WASP6 segment is obtained by distributing the GWLF runoff flows from the east and west branch sub-watersheds and main stem watershed into the east and west branches and main stem of the creek, respectively. Besides the runoff flow from the GWLF output, an upstream boundary flow of 15 cubic feet per second (cfs) is assigned to upstream of the east and west branches that represents a minimum base groundwater flow based on the GWLF calibration and validation. This base flow was determined from calibration of the GWLF model to dry weather conditions for the 1993 period and validated through GWLF application to dry weather conditions for the 2000 period.

Besides the runoff inflow and boundary flow, there are also some incoming flows from municipal WWTP discharges. These include the Filtration Plant, Michigan City Sanitary Station, Friendly Acres Mobile Home Park (MHP), Autumn Creek MHP, and Indian Springs Subdivision. The data source for these flows is DMR data for the year 2000.

Point Source Loads

Point sources of *E. Coli* into Trail Creek mainly come from municipal discharges, including Michigan City Sanitary Station, Friendly Acres MHP, Autumn Creek MHP, and Indian Springs Subdivision. Michigan City does have combined sewer overflows (CSO) but there were no reported events in 2000. CSO events in Michigan City have improved significantly since 1990 (Table 6) and currently the city is implementing a Long Term CSO Control Plan (April 24, 2002) that includes sewer separation to reduce combined sewers in the District's service areas.

Table 6
MICHIGAN CITY SANITARY DISTRICT CSO HISTORY

Year	**Number of Annual CSO Overflows (Outfall 002)**
1990	47
1991	24
1992	2
1993	32
1994	3
1995	0
1996	19
1997	14
1998	1
1999	0
2000	0
2001	1

Discharge monitoring report (DMR) data provides monthly flow for these point sources but *E. Coli* concentrations for only the Sanitary Station. Average effluent flow for the year 2000 was 4.8 million gallons per day (MGD) for the Sanitary Station, 0.015 MGD for Friendly Acres MHP, 0.010 MGD for Autumn Creek MHP, and 0.018 MGD for Indian Springs Subdivision. Average *E. Coli* levels from the Sanitary Station during 2000 ranged from 2-23 #/100ml (7 month average of 12 #/100mL) with maximum levels ranging from 6-200 #/100mL during the months of April through October. In addition, disinfection at these wastewater treatment plants (WWTP) occurs during the months of April through October, which coincides with the State *E. Coli* standard being applied during these months. For the WWTPs where no *E. Coli* information was available, the Sanitary Station average *E. Coli* level of 12 #/100mL was used during the months of April through October. It was assumed that 2 orders of magnitude bacterial kill is achieved with disinfection and, therefore, for the months when disinfection at the WWTPs is not occurring (November through March), *E. Coli* levels were assigned 2 orders of magnitude greater than during the disinfection months (i.e., 1,200 #/100mL). Typical percent removal of bacteria during the disinfection process of treated wastewater is 98-99% (Metcalf & Eddy, 1991), which would result in non-disinfection *E. Coli* levels of approximately 1,200 #/100mL or lower. In addition in the USEPA document *Municipal Wastewater Disinfection* (1986), initial *E. Coli* levels before disinfection at secondary treatment ranged from 10^3-10^5 #/100mL. Although there is a range in *E. Coli* levels before disinfection, this assumption will not affect model calculations during the important recreational season (March to October) when the WWTPs are disinfecting to *E. Coli* levels well below 100 #/100mL. Table 7 presents the *E. Coli* point source loads for the year 2000 used in the water quality modeling.

Table 7
POINT SOURCE *E. COLI* LOADS (#/DAY) IN 2000

Month	Michigan City Sanitary Station	Friendly Acres MHP	Autumn Creek MHP	Indian Springs Subdivision
Jan	1.77×10^{11}	6.81×10^{8}	4.04×10^{8}	6.81×10^{8}
Feb	1.77×10^{11}	6.81×10^{8}	4.04×10^{8}	8.18×10^{8}
Mar	1.82×10^{11}	6.81×10^{8}	4.50×10^{8}	8.63×10^{8}
Apr	9.46×10^{8}	6.81×10^{6}	4.59×10^{6}	9.54×10^{6}
May	4.25×10^{9}	6.81×10^{6}	4.36×10^{6}	7.72×10^{6}
Jun	5.57×10^{9}	6.81×10^{6}	5.54×10^{6}	9.08×10^{6}
Jul	3.23×10^{9}	6.81×10^{6}	5.00×10^{6}	8.63×10^{6}
Aug	1.70×10^{9}	6.81×10^{6}	4.09×10^{6}	8.63×10^{6}
Sep	3.86×10^{8}	6.81×10^{6}	5.45×10^{6}	7.72×10^{6}
Oct	1.42×10^{9}	6.81×10^{6}	4.09×10^{6}	5.90×10^{6}
Nov	1.82×10^{11}	6.81×10^{8}	4.54×10^{8}	7.72×10^{8}
Dec	1.77×10^{11}	6.81×10^{8}	6.36×10^{8}	7.27×10^{8}

Nonpoint Source Loads

WASP6 has an optional nonpoint source linkage option. Nonpoint source loads were calculated daily for each segment as the product of the GWLF runoff flow and *E. Coli* concentration in each segment. GWLF runoff flow was distributed evenly for the segments in each branch. For example, each of the 10 segments in the west branch has a runoff flow equal to one tenth of the GWLF runoff flow for the west branch sub-watershed. *E. Coli* concentrations in the runoff were estimated from the Trail Creek *E. Coli* survey data at upstream stations that reflect land use types associated with agriculture and forested areas. Measurements at stations in the agricultural and forested area of the west and east branches (4.72W and 6.46E-GD) were chosen to represent the runoff concentrations in these sub-watersheds. Since *E. Coli* concentrations were usually positively related to river flow, correlation analyses were performed on *E. Coli* concentrations at these stations versus flow at the active USGS gaging station. Figure 9 presents the *E. Coli* and flow correlation for the sampling stations. The data at station 4.72W indicated a positive correlation while the data at station 6.46E-GD suggests a random pattern not related to river flow. The equation developed for station 4.72W ($E.\,Coli = 9.52 \times Flow^{1.42}$) and USGS flow at the active gaging station were applied to derive the *E. Coli* concentrations in year 2000 for the WASP6 model input for the west branch. For the east branch, the observed data distribution as represented by the median and variation of the data were used to develop random *E. Coli* daily concentrations for the year 2000. This random distribution was developed to maintain the same distribution observed in the data, which is presented in Figure 10. These generated concentrations for the west and east branches were coupled with the GWLF runoff flows to generate nonpoint source loads into the WASP6 model. For the main branch, an *E. Coli* concentration of 25,000 #/100mL was assigned to calculate the runoff load. This *E. Coli* value is within the range for urban storm water runoff, which can range from approximately 100 to 250,000 #/100mL, but was also based on reproducing observed *E. Coli* levels in the main branch when upstream (east and west branch) loadings were minimal. Table 8 presents the nonpoint source *E. Coli* loads for the calibration period.

Table 8

NONPOINT SOURCE *E. COLI* LOADS (#/DAY) IN 2000

Month	East Branch	West Branch	Main Branch	Baseflow	Total
Jan	0.00	0.00	0.00	7.34×10^{10}	7.34×10^{10}
Feb	1.49×10^{9}	6.61×10^{10}	3.91×10^{12}	7.34×10^{10}	4.05×10^{12}
Mar	0.00	0.00	4.30×10^{12}	7.34×10^{10}	4.37×10^{12}
Apr	5.49×10^{10}	1.12×10^{12}	1.10×10^{13}	2.20×10^{11}	1.24×10^{13}
May	1.83×10^{9}	3.15×10^{10}	2.33×10^{12}	3.67×10^{11}	2.73×10^{12}
Jun	7.56×10^{11}	9.49×10^{12}	3.01×10^{13}	3.67×10^{11}	4.07×10^{13}
Jul	8.91×10^{10}	8.25×10^{11}	2.90×10^{12}	3.67×10^{11}	4.18×10^{12}
Aug	7.81×10^{5}	1.04×10^{7}	3.36×10^{9}	3.67×10^{11}	3.70×10^{11}
Sep	6.74×10^{9}	3.65×10^{11}	2.09×10^{12}	2.20×10^{11}	2.68×10^{12}
Oct	2.49×10^{4}	7.79×10^{5}	3.36×10^{12}	7.34×10^{10}	3.44×10^{12}
Nov	0.00	0.00	6.21×10^{12}	7.34×10^{10}	6.28×10^{12}
Dec	1.02×10^{7}	4.73×10^{8}	4.97×10^{12}	7.34×10^{10}	5.05×10^{12}

Boundary Conditions

Boundary conditions for *E. Coli* at the most upstream segment in the east and west branches were assigned a nominal value between 100 and 500 #/100mL to reflect background loadings with associated groundwater base flow and other unidentified inputs. The months of October through March were assigned a value of 100 #/100mL, April and September were assigned 300 #/100mL, and May through August were assigned 500 #/100mL. These boundary condition values were based on calibration of the WASP6 model to downstream locations and also based on observed *E. Coli* levels at upstream stations in the east and west branches during dry weather conditions.

<u>Initial Conditions</u>

Initial conditions are usually not critical if data is not available at the beginning of the model simulation because the assigned values quickly equilibrate to levels that represent the loading and transport conditions in the model for systems with very short residence time, as is the case in Trail Creek. Initial conditions are more important in system with long residence time (e.g., lakes or estuaries) where the initial assignment may have an impact on the model calculations. Consequently an initial conditions of 100 #/100mL was assigned.

<u>Temperature Time Functions</u>

The time functions in the *E. Coli* model were three temperature functions for the three branches. The temperature data is from the IDEM *E. Coli* sampling database and monthly averages were assigned in the three branches based on the observed data.

<u>Constants</u>

The only constants used in the model were the die-off rate for *E. Coli* and the temperature adjustment coefficient for the decay. The most commonly used approach in modeling bacteria disappearance is a simple first-order reaction equation:

$$\frac{dC}{dt} = -kC \qquad \text{or} \qquad C(t) = C_0 e^{-kt}$$

where:

- C = *E. Coli* concentration, #/100mL;
- C_0 = initial *E. Coli* concentration, #/100mL;
- $C(t)$ = *E. Coli* concentration at time t, #/100mL;
- k = *E. Coli* die-off rate at ambient temperature, day^{-1}; and
- t = exposure time, days.

Factors affecting *E. Coli* die-off rates can be physical, physicochemical, and biochemical-biological, such as solar radiation, temperature, sedimentation, nutrient deficiencies, predation, pH, and/or chemical toxicity. Among all the factors, temperature is probably the most generally influential factor modifying all other factors (Bowie, G. L. etc, 1985). The equation for temperature correction for the decay rate, k, in the WASP6 model is the following:

$$k = k_{20}\boldsymbol{q}^{T-20}$$

where:

k_{20} = die-off rate at 20°C; and
θ = temperature correction factor.

Typical ranges for the *E Coli* die-off rate range from 0.005 hr^{-1} (0.12/day) in the Tennessee River (deep system) in the summer to 1.1 hr^{-1} (26/day) in the Glatt River (Bowie, G. L. etc, 1985). An *E. Coli* die-off rate of 1.5/day and a typical temperature correction factor (θ) of 1.07 was used for the model calibration. The die-off rate and temperature correction factor, model input requirements, were assigned based on literature reported ranges and modeling studies in similar watersheds.

4.2.3 Model Calibration

Figures 11a through h present the WASP6 model time series results as compared to observed data for the year 2000 on both an arithmetic and logarithmic scale for *E. Coli*. The black line in these figures represents the WASP6 daily output and the observed values are presented as filled black circles. There were a number of rainfall events occurring in the year 2000, but most of the samples were collected before or after the events and, therefore, little data was available during a storm event to properly test the model. This sampling artifact is presented in Figures 12a and b for the model and data comparisons in June and September when significant rainfall occurred. Overall the model reasonably reproduced the observed data in the east, west and main branches. Observed data near the mouth of the creek were typically lower than the WASP6 results but this is most likely due to additional dilution of the creek from Lake Michigan not represented in the model. Also, the model did not reproduce some of the higher observed values in June in the main branch but this may suggest that there is a missing *E. Coli* source entering the creek, as these high values are not observed upstream. In general, the WASP6 model reasonably reproduced the observed data given the limitations in the sampling for *E. Coli* in Trail Creek.

There were a few sampling events that came closer to capturing a storm event and these are presented in Figures 12a and b for June and September, respectively. These figures present the observed *E. Coli* data, WASP6 model output and rainfall data for the months of June and September at a number of stations in Trail Creek. These figures highlight the typical creek sampling before and after storms and also that the model does capture these non-storm periods fairly well. The storm event in the middle of June was not completely reproduced by the WASP6 model but this may be due to a missing source as discussed above. The storm events in September were better reproduced by the model and, therefore, highlight that the model is capable of representing *E. Coli* levels in Trail Creek.

Another way to compare model output with observed data is through comparison of probability distributions. This type of comparison highlights whether the model reproduces the observed variation observed in the data. Figures 13a through b present the model calculated and observed probability distributions of *E. Coli* concentrations at various stations in the east, west and main branches of Trail Creek. In order to generate the model distributions, model output was extracted during the months when sampling occurred at the respective monitoring stations. In general, the model calculated median and variation compared fairly well with the observed data indicating that although exact timing may not be reproduced in the model, the observed variation is reproduced at most stations.

4.2.4 Model Sensitivity

In order to investigate the sensitivity to the main branch *E. Coli* runoff concentrations, two additional model runs were completed. These sensitivities were chosen because the main branch runoff concentration was partially estimated from observed data in the watershed and typical urban storm water runoff concentrations can vary over orders of magnitude. Two sensitivities were completed for a main branch runoff concentration of 10,000 #/100mL and 50,000 #/100mL, the figures of which are contained in Appendices 1 and 2, respectively. In general, these figures highlight the importance of the urban storm water runoff concentration on the calculated *E. Coli* concentrations in the main branch of Trail Creek. The higher runoff concentration (50,000 #/100mL) improves the model fit of the observed data in June but also causes higher calculated concentrations than observed during other times of the year. The opposite is true for the lower runoff concentration (10,000 #/100mL). These results indicate that better definition of *E. Coli* concentration from urban storm water runoff for the main branch of Trail Creek should be investigated.

Section 5.0
CONCLUSIONS

The Trail Creek Watershed model reasonably reproduced observed creek flow and *E. Coli* concentrations given the limitations present in both the flow and *E. Coli* databases. Although the models are not rigorously calibrated due a lack of acceptable flow and *E. Coli* data, the models can be used to assess current conditions and to develop allocation and implementation strategies for Trail Creek. That is, the GWLF and WASP6 models were developed with the best information available at this time and the development of point source wasteload allocations (WLA) and nonpoint source load allocations (LA) for the Trail Creek *E. Coli* TMDL is practical and supported by the available data.

Section 6.0
RECOMMENDATIONS FOR POTENTIAL FUTURE TMDL WORK

Subsequent to the implementation of the Trail Creek TMDL, further refinement of the model and implementation strategies may be needed. If so, the following recommendations are presented.

- Additional data collection throughout the watershed should be completed to better define *E. Coli* levels before, during and after storm events. This is aimed at better defining both storm and base loadings of *E. Coli* from the various sources in the watershed and should be focused on storm event monitoring rather than periodic monitoring of the watershed for overall water quality assessment.

- Re-location or installation of a flow gage further upstream in the watershed should be considered for better measurement of watershed flows that are not influenced by Lake Michigan. An alternate option may be to collect watershed flow data during *E. Coli* storm event monitoring.

- Additional model calibration for both the GWLF and WASP6 models should be considered to further test the models during storm events. The additional storm event data collection can be used to complete this additional model testing.

Section 7.0
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APPENDIX 1

MAIN BRANCH RUNOFF SENSITIVITY
(10,000 #/100mL)

APPENDIX 2

MAIN BRANCH RUNOFF SENSITIVITY (50,000 #/100mL)